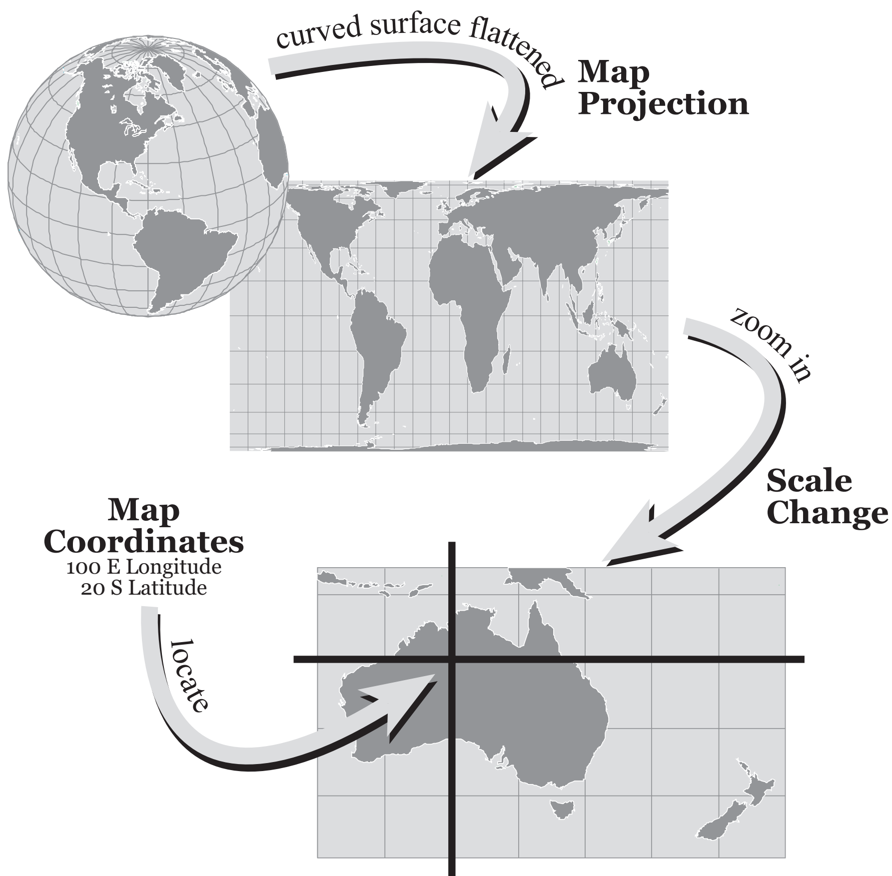
Geographic Framework

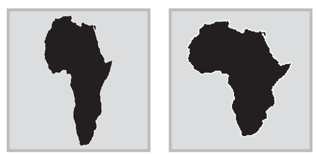
We use maps to flatten the curved surface of the earth, shrink it down to a size we can handle, and systematically locate things.

We make maps for particular reasons, and those reasons guide the selection of a particular geographic framework - a map projection (which gets us flat), an appropriate scale, and a coordinate system (which helps us locate things on the map).

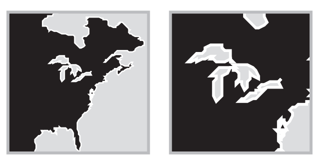


Choosing a **geographic framework** involves:

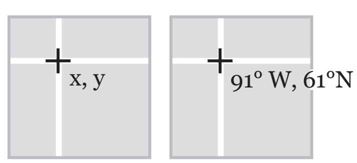
1 **Map Projection:** Flattening the earth's curved surface, and the resulting distortions of area, shape, distance, or direction



2 **Map Scale:** How much of the earth to show, and at what size?

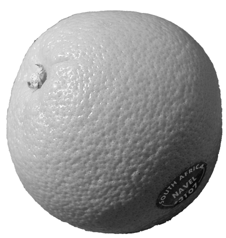


3 **Map Coordinates:** Graph-like grids placed on the earth to assist with locating phenomena

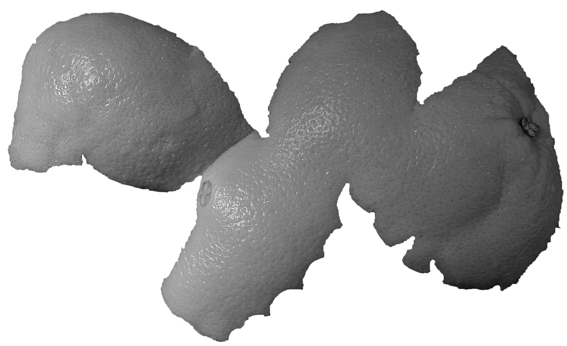


1 Map Projection

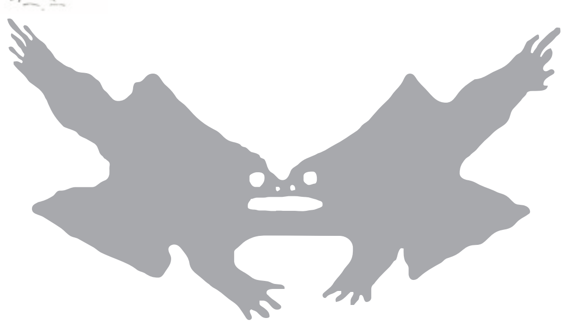
Our earth's surface is curved. Most maps are flat. Transforming the curved surface to a flat surface is called map projection. All projected maps are flat, compact, portable, useful, and always distorted. Any curved surface gets distorted when you flatten it.



An orange peel *tears* when you peel and flatten it.



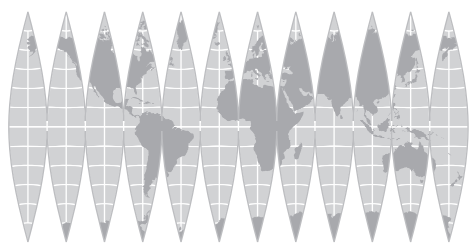
A toad skin *tears* when you peel and flatten it.



Strike flat the thick rotundity o' th' world!
William Shakespeare, *King Lear*

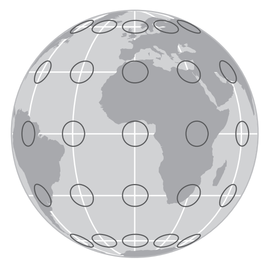
The surface of the Earth *tears* when you peel and flatten it. Peel a globe and you will get globe gores (below).

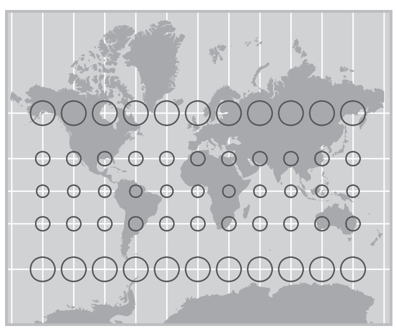
Most map projections stretch and distort the earth to "fill in" the tears. The Mercator projection (bottom) preserves angles, and so shapes in limited areas, but it greatly distorts sizes. Look at the size of Greenland on the globe compared to the Mercator.



distorting circles

In the 19th century, Nicolas Auguste Tissot developed his "indicatrix," which can be used to evaluate map projection distortion. Imagine perfect circles of the same size placed at regular intervals on the curved surface of the earth. These circles are then projected along with the earth's surface. Distortions in the size and shape (angular distortion) of the circles show the location and quality of distortions on the projected map.

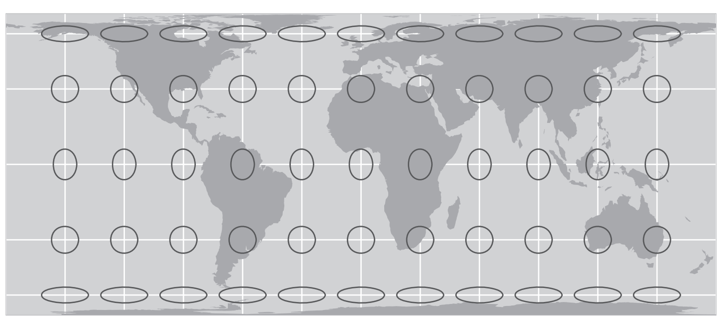




Mercator Map Projection:
Preserves shapes, distorts areas.

Left: Tissot's circles change *size* as you move north and south of the equator on the Mercator map projection. The more distorted the circles, the more distorted the areas of the land masses. Circle *shapes* are not distorted.

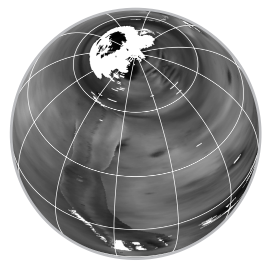
Below: Tissot's circles change *shape* over the surface of this area-preserving map. The more distorted the circles, the more distorted the shapes of the land masses. Circle *sizes* are not distorted.

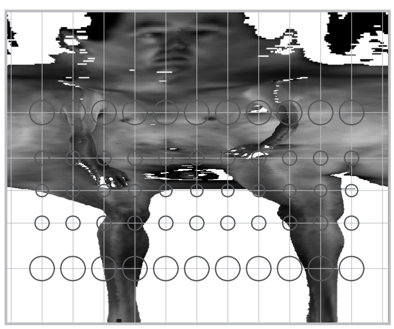


Equal-Area Map Projection: Preserves areas, distorts shapes.

distorting bodies

We can use Bill Outcault's projected body to more clearly see map projection distortions. Whenever you look at a projected map of the earth, think about what is happening to the earth. Cripes!

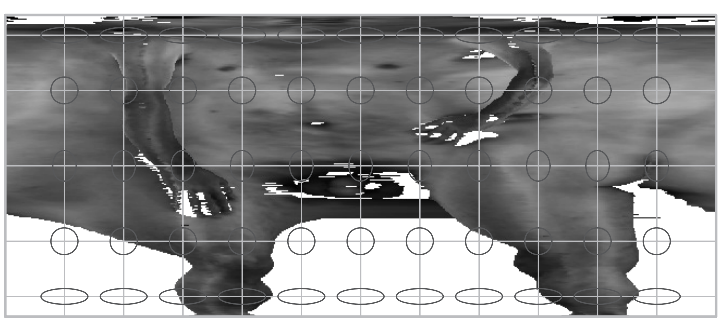




Left: Tissot's circles change size as you move north and south of Bill's waist on the Mercator map projection. The more distorted the circles, the more distorted the areas of the body.

Below: Tissot's circles change shape over the surface of this area-preserving map. The more distorted the circles, the more distorted the shapes of different parts of the body.

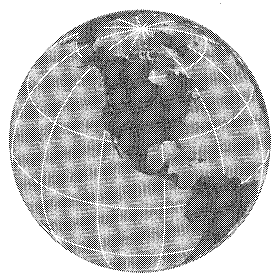
Mercator Map Projection:
Preserves shapes, distorts areas.

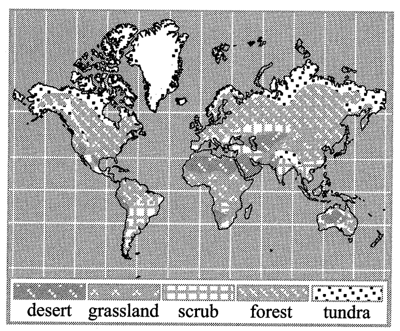


Equal-Area Map Projection: Preserves areas, distorts shapes.

distorting data

Mappable data is always associated with a location on the earth's surface. That is, mappable data is always tied to the grid. Because this grid gets distorted when it's projected from the curved surface of the earth to the flat surface of the map, the data tied to the grid gets distorted too. ***Projections matter because of what they do to our data!*** *Since map projections do things to our data, it's important that what they do to the data clarifies, not muddies, it.*

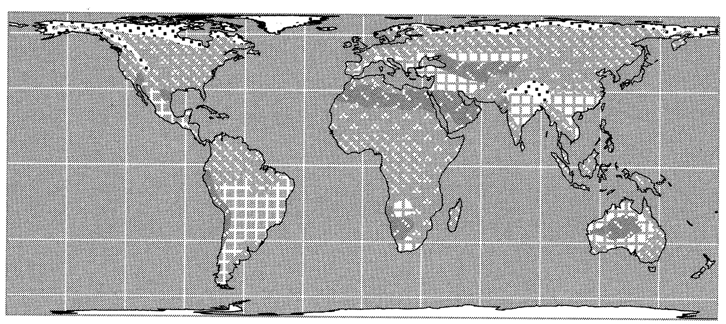




Mercator Map Projection: Preserves shapes, distorts areas.

Left: A map of vegetation on a **Mercator** distorts the data. Northern vegetation types are greatly expanded in area compared to vegetation types near and south of the equator. This visually suggests the global dominance of northern vegetation types, which is not correct.

Below: The same vegetation data on a map projection that **does not distort areas.** But now shape is distorted! You have to be smart with projections and understand tradeoffs. In this case, with area vegetation data, you are better off distorting shapes and not areas.



Equal-Area Map Projection: Preserves areas, distorts shapes.

distorting layers

We often impose multiple layers of mappable data on top of one another. Since all mappable data are tied to a grid, we have to have the same projection for each layer of data for all of the layers to align properly. This is important when combining digital layers in GIS, but also when compiling data from existing map sources. Always try to learn the projection of your data sources.

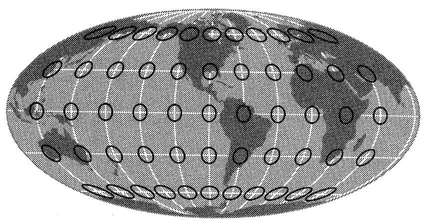
Two map layers, each with a *different* projection: an **Albers equal area in light grey** and a **Mercator conformal in dark grey.** The data will not properly align! This causes visual and computational problems.

Use GIS tools to *transform* one of the layers so both layers have the same projection.

what projections preserve

No map projection preserves the attributes of a globe, which maintains area, shape, distance, and direction. Map projections can preserve one or two of the attributes of the globe, but not all. Select a map projection that makes the best sense for your data.

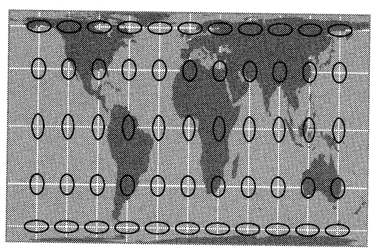
preserving area



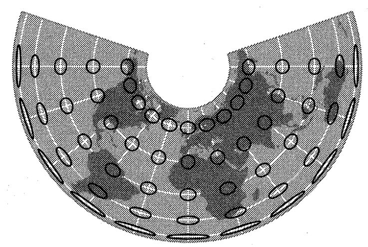
Some projections preserve size. This means that areas which are the same size on the globe are the same size on the map.

Area preserving, or equal-area map projections, are a good default for most maps.

Mollweide Projection
Oval shape, preserves area. Rounded map shape suggests the roundness of the earth. Projection can be **recentered** to minimize shape distortions of regions of greatest interest.



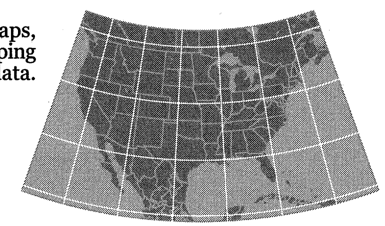
Gall Projection: Also known as the Peters Projection. This area-preserving projection's straight grid lines make north-south relationships straight-forward. Rectangular shape makes it easy to fit into page layouts. Excellent projection for illustrating the shape distortions inherent in area-preserving map projections, and the area distortions inherent in shape-preserving projections.

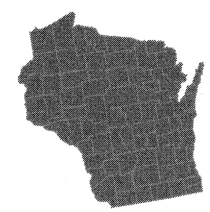


Albers Equal-Area Projection

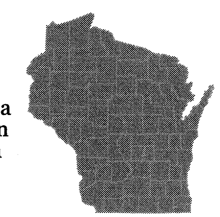
A common area-preserving map projection. **Poor** for world scale maps because of shape distortion and peculiar form. However, **recentering** on the area of interest (the U.S.) and selecting **part of the earth** (continent, country) results in an equal-area map with minimal shape distortion.

Good for regional maps, particularly when mapping area data.



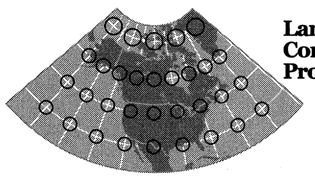


If you zoom in and isolate one area you may have to recenter again: in this case, center the projection on Wisconsin (70° W).

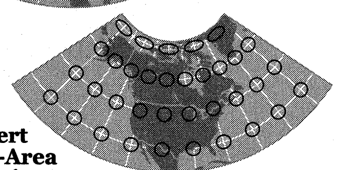


what projections preserve

preserving shape



Lambert Conformal Projection

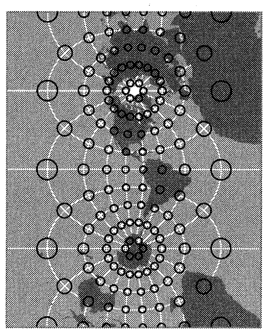


Lambert Equal-Area Projection

At sub-global scales distortions of area and shape are not as visually evident.

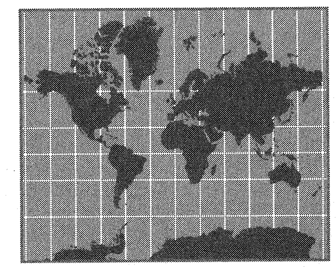
Saying that certain map projections preserve shape is not technically correct, but makes sense to normal people. As long as you are away from areas of high distortion, the shapes of contintents look OK. Conformal map projections preserve angles (around points) and therefore shape in small areas. Sizes are consequently distorted.

Conformal map projections are good for mapping regions and continents, especially when statistical data are involved.



Transverse Mercator

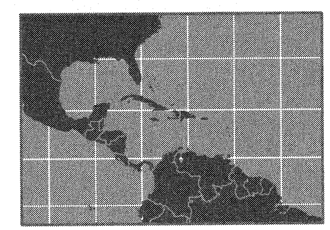
On the Mercator projection, scale is true along the equator. When that projection is recentered sideways along a meridian - or line of longitude - scale is true along that meridian. This recentered projection is known as the Transverse Mercator and is the basis for the Universal Transverse Mercator coordinate system. When areas **a few square miles in size** are mapped using this projection, they are effectively free of all distortion.

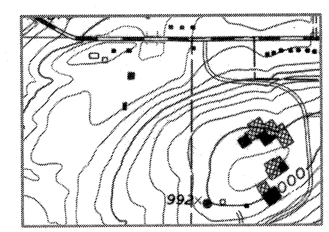


Mercator Projection

The Mercator is one of the few conformal world projections. Its distortions of sizes are nasty and it is a **poor** choice for a world map.

Good for regional sailing and flying charts, as any straight line drawn on a Mercator is a true compass bearing.



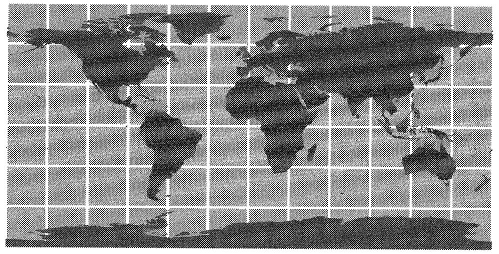


Good for maps of very small areas. Many detailed topographic maps are based on the (transverse) Mercator.

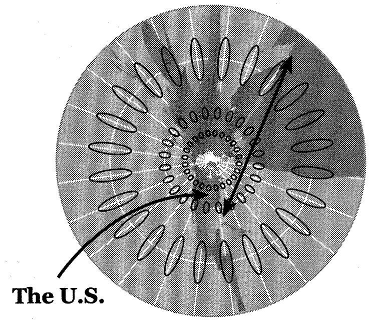
preserving distance / direction

Stretch a piece of string between two points on a globe, and you will get the shortest distance between the points (called a great circle). Some projections preserve such distance relations: a straight line between two points on the map is the shortest distance between those two points on the earth. Distance relations cannot be preserved on equa-area maps.

Direction can be preserved on area-, shape-, or distance-preserving map projections.



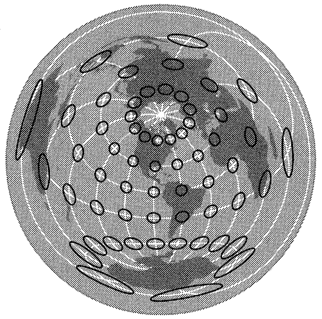
Geographic Coordinate System, aka the "Geographic Projection." The default projection in a popular GIS software package, similar to the Plate Carrée projection. This unpleasant item preserves nothing but distance, principally for north-south measurements. This projection is increasingly common, especially on internet mapping sites, where it distorts the data mapped on it.



Gnomonic Projection: A straight line drawn anywhere on a Gnomonic projection is a great circle route, the shortest distance between two points. Terrifying distortions of area and shape and the inability to show more than half the earth at a time limit other uses of this projection.

Azimuthal Equidistant Projection

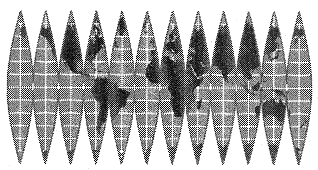
Planar (azimuthal) map projections preserve directions (azimuths) from their center to all other points. The azimuthal equidistant projection also preserves *distance*: a straight line from the projection center to any other point represents accurate distance, in addition to correct direction and the shortest route. **Great** for offices of travel agencies when centered on their hometown.



Poor for showing anything but distances from a point. Areas and shapes are wildly exaggerated as you move from the center.

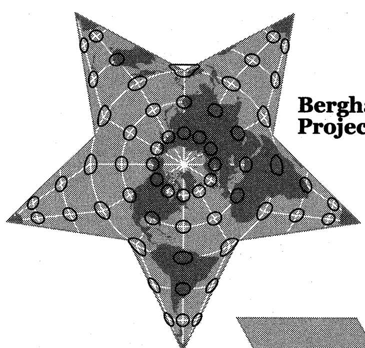
what projections preserve

interruptions

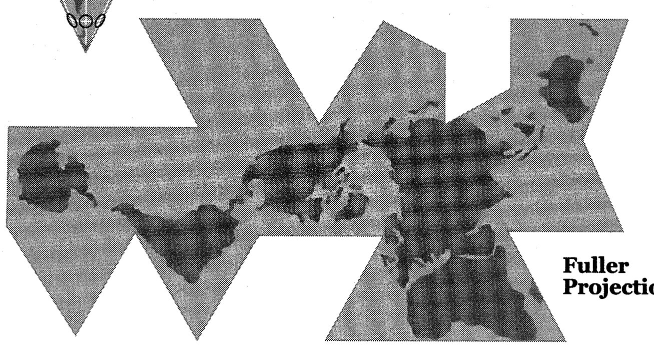


Globe gores, peeled from a globe and flattened, are akin to interrupted map projections. Interrupted map projections minimize distortions on the uninterrupted part of the map, and are typically used on maps of the entire earth.

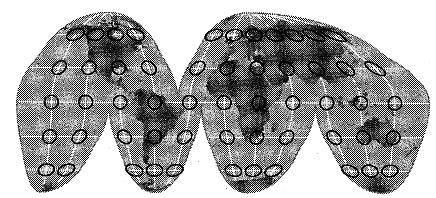
Interrupted map projections are commonly used for maps of global statistical data. They have also been used as cute icons (Berghaus Star) and as the basis of "cut and assemble" globes (Fuller). The Berghaus is equidistant north of the equator. The Fuller has constant scale along the edges of all twenty of the triangular pieces. Within each of these triangles, size and shape are well presented.



Berghaus Projection

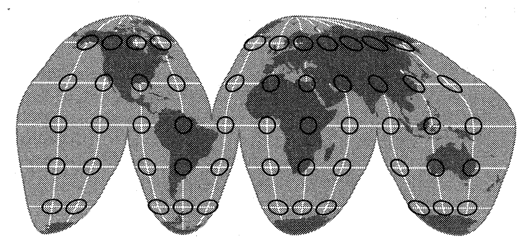


Fuller Projection

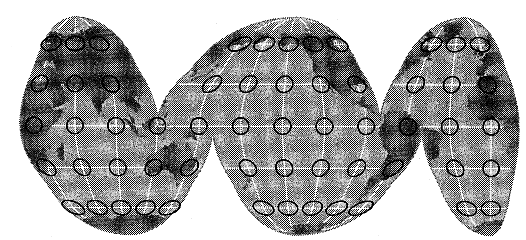


Goode's Homolosine Projection

Goode's is a common interrupted map projection used for world maps of statistical data. The projection does not distort areas, and shape distortions in the uninterrupted areas of the map are minimized. *Interruptions can be moved:* a map for ocean phenomena can interrupt land areas:



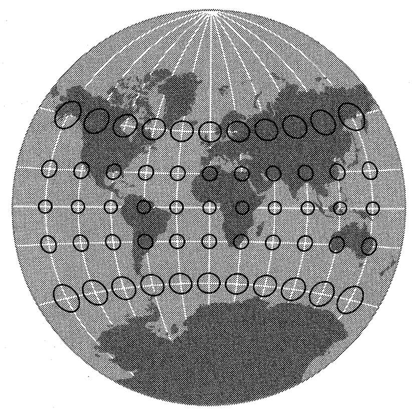
Poor interruptions for mapping ocean phenomena



Goode interruptions for mapping ocean phenomena

what projections preserve

most of everything



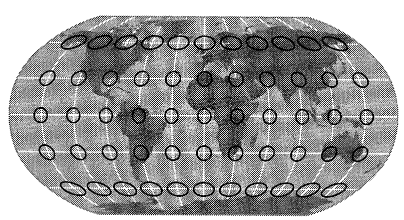
Map projection is most visible at a global scale, where distortions of areas and shape are most evident. Area-preserving projections often badly distort shapes, and shape-preserving projections area. But there is an alternative.

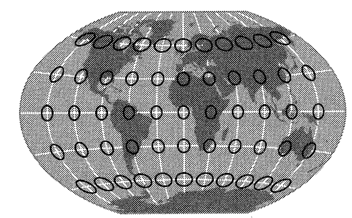
Compromise map projections distort area and shape a bit, but neither too badly. Compromise is ***a good thing.***

The **Van der Grinten Projection** does not preserve shape or area, but minimizes their distortions in all but polar regions. Usually the polar regions are lopped off and the map presented as rectangular.

Robinson Compromise Projection

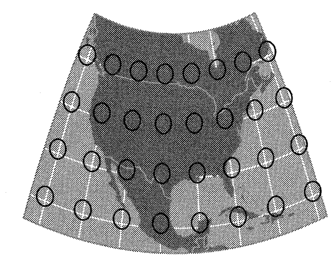
Arthur Robinson's map projection preserves neither area nor shape, but reduces the distortion of both. The projection has rounded sides, suggesting the spherical earth, and avoids excessive distortion near the poles.





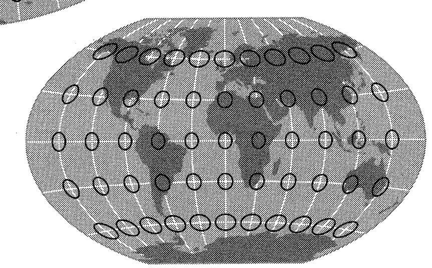
Winkel Tripel Compromise Projection

This projection resembles the Robinson, but it has less areal exaggeration in the polar regions. The Winkel Tripel is the default world projection for the National Geographic Society.



Poor for regional or local scale maps because of area and shape distortion.

Good for a general world map and for mapping global phenomena



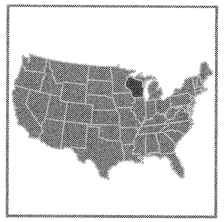
2 Map Scale

The earth is big. Maps are small. Map scale describes the difference, verbally, visually, or with numbers. Map scale will be determined by your goals for your map. Map scale affects how much of the earth, and how much detail, can be shown on a map.

verbal

visual

small scale

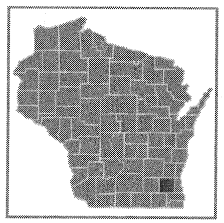


1 inch = 2500 miles

0 — 3000 mi

1 cm = 1584 kilometers

0 — 4000 km

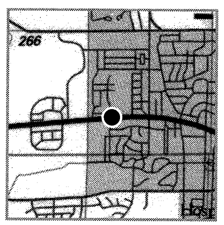


1 inch = 350 miles

0 — 400 mi

1 cm = 220 kilometers

0 — 800 km

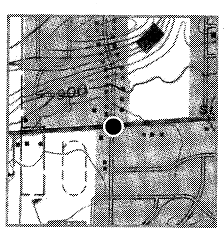


1 inch = 1.6 miles

0 — 2 mi

1 cm = 1 kilometer

0 — 3 km



1 inch = .4 mile

0 — 1/2 mi

1 centimeter = .25 kilometer

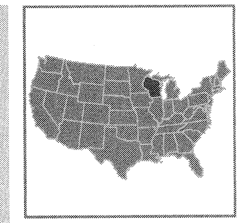
0 — 1 km

large scale

numerical

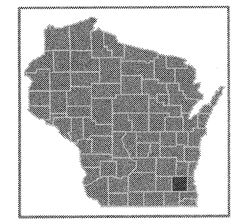
1 : 155,000,000

A representative fraction (RF) shows the proportion between map distance and earth distance for *any unit of measure.* **1 inch** on the map is **155 million inches** on the earth. **1 cm** on the map is **155 million** cm on the earth.



1 : 22,000,000

Distortions from map projections become less visually noticeable at regional and local scales. These distortions may become evident when combining map layers with different projections in GIS.

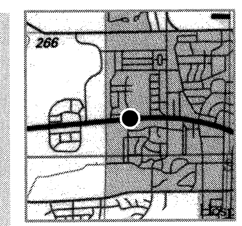


1 : 100,000

Divide a representative fraction:

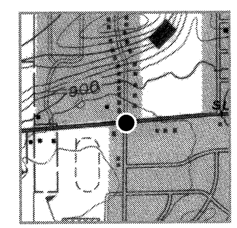
1 / 100,000 = .00001
1 / 24,000 = .00004

The former is *smaller* than the latter: thus 1:100,000 is *smaller* scale than 1:24,000 (*larger* scale).



1 : 24,000

Larger-scale maps show *more detail* but of a *limited area.* Map projection distortions are less evident and distance is relatively accurate over the entire map.

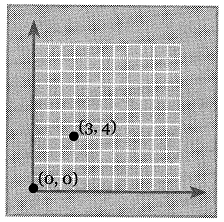


small scale

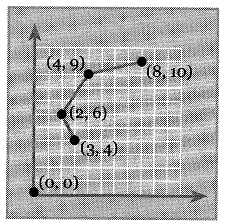
large scale

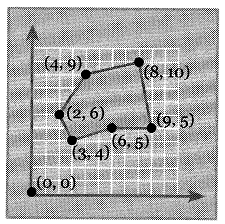
Map Coordinates

Map coordinates are a pair of numbers or letters which locate a point on a map. Linear features, such as rivers, are located as a string of connected point coordinates. Area features, such as a country, are located as a closed string of connected point coordinates. There are many different map coordinate systems.



Map coordinate systems are based on the idea of a grid. A point is given a *location* on the grid in relation to an origin (0, 0). Lines and areas are defined by connecting a series of points.





Where is (0, 0)?

Where, on earth, should the origin (0, 0) be? If Washington, DC, is the origin, then all other locations are in relation to Washington. *Different coordinate systems have different origins.*

Area covered?

How much of the earth is covered by the coordinate system? All of it? Part of it? *Different coordinate systems cover all or only part of the earth.*

Flat or sphere?

Coordinate systems which cover part of the earth assume a flat earth to take advantage of the easier *planar geometry*. Coordinate systems which cover all of the earth assume *spherical geometry*.

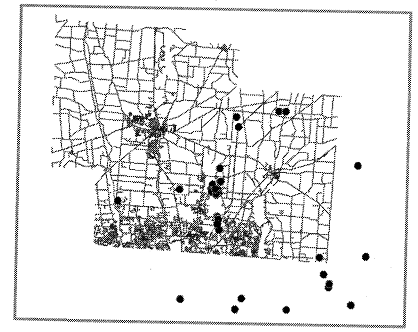
Units?

Coordinate systems can be in English units (feet), metric units (meters), or degrees. *Different coordinate systems have different units of measurement.*

matching coordinates

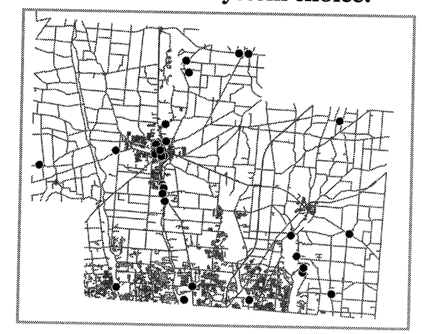
Map readers may need to understand common map coordinate systems to locate features on maps. Map makers need to understand map coordinate systems. When two or more digital maps are combined (as layers in GIS) they must have the same coordinate system, or they will not align properly. When new data are created (GPS or digitizing) they must be in the same coordinate system as other digital maps they are to be used with.

Poor coordinate system choice:



Delaware County, OH: A digital map of county roads is in the State Plane Coordinate System (SPCS). A second digital map shows county buildings on the National Historical Register. It uses UTM (Universal Transverse Mercator) coordinates. Combining these maps in GIS without a common coordinate system results in misaligned map layers.

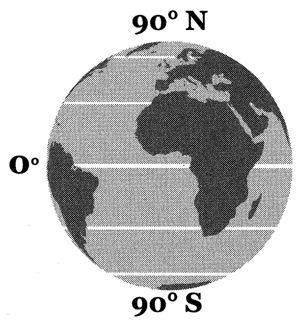
Good coordinate system choice:



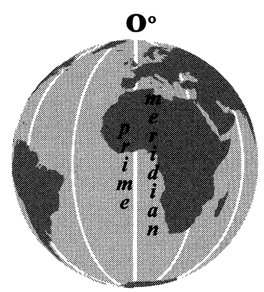
Transforming the Historical Register layer (using GIS tools) into SPCS allows the two maps to be properly aligned. SPCS is chosen in this case because many other Delaware County digital maps use SPCS (a common choice for regional planners in the U.S.).

latitude & longitude

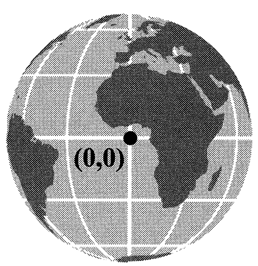
Latitude and longitude cover the entire earth with one system and a single origin. In this system, locations are specified in degrees, minutes, and seconds.



The equator is the origin for **latitude.** Lines of latitude are called **parallels.** Parallels run east-west, measuring 90° north and 90° south of the equator. Parallels never converge: one degree of latitude is always 69 miles (111 km).



Greenwich, England, is the origin (prime meridian) for **longitude.** Lines of longitude are called **meridians.** Meridians run north-south, measuring 180° east and 180° west of the prime meridian. Meridians converge at the poles: one degree of longitude at the equator is 69 miles (111 km); one degree of longitude at the poles is 0 miles/km (a point).



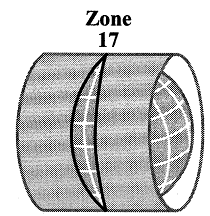
The single origin (0, 0) is off the coast of Africa. Coordinates fall into one of four quadrants to the N/S (latitude) and E/W (longitude) of this origin.

Latitude/Longitude is measured in *degrees:* there are 60 minutes in 1 degree and 60 seconds in 1 minute.

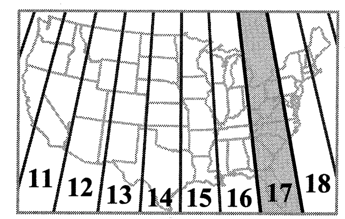
Latitude/Longitude is used when you need a single coordinate system for the entire earth.

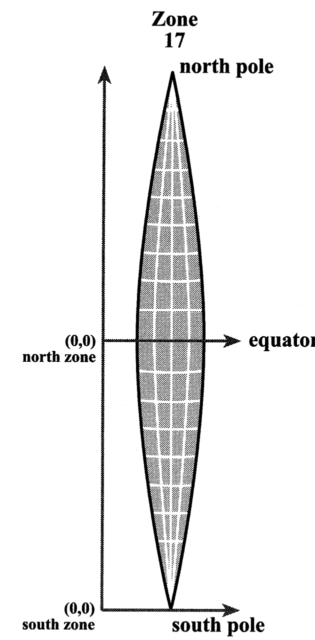
universal transverse mercator

The Universal Transverse Mercator (UTM) coordinate system is associated with the U.S. military. UTM, based on the "transverse" (sideways) Mercator projection, covers the entire earth, which is divided into 60 zones, each 6° wide, running from pole to pole. Planar geometry (a flat earth) is assumed.



UTM zones are widest at the equator and narrow to a point at the poles. Ten zones (10 - 19) cover the continental U.S.





Each 6°-wide zone has a North and South zone. An origin (0, 0) is established to the south-west of each zone, so that all coordinates in the zone are positive.

UTM is measured in *meters.* A point is located in terms of how many meters east and north it is from the origin.

UTM is used by environmental scientists, the military, and any other professions who work at a regional or local scale but need their maps to coordinate with maps of other areas on the earth.

state plane coordinates

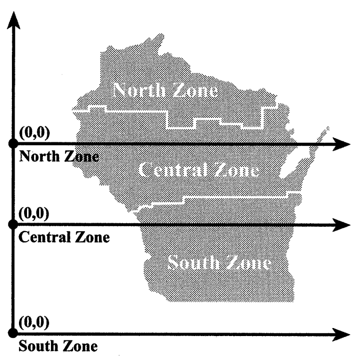
The State Plane Coordinate System (SPCS) was developed by the U.S. Coast and Geodetic Survey. SPCS is used only in the United States, which is divided into several hundred areas, each with its own coordinate system. Since each area is relatively small, planar geometry (a flat earth) is assumed. Similar coordinate systems are used in other parts of the world.

Small U.S. States have a single SPCS zone; larger states are divided into several zones. No zone crosses a state boundary.

Wisconsin has three SPCS zones. An origin (0, 0) is established to the south-west of each zone, so that all coordinates in the zone are positive.

SPCS is measured in *feet*. A point is located in terms of how many feet east and north it is from the origin.

SPCS is used by planners, urban utilities, environmental engineers, and other professions who work at a regional scale.



An unseen ruler defines with geometry
An unrulable expanse of geography
An aerial photographer over-exposed
To the cartologist's 2D images knows
The areas where the water flowed
So petrified, the landscape grows
Straining eyes try to understand
The works, incessantly in hand
The carving and paring of the land
The quarter square, the graph divides
Beneath the rule a country hides

Interrupting my train of thought
Lines of longitude and latitude
Define and refine my altitude

Wire. *Map Ref. 41°N 93°W.* (song lyrics, 1979)

"According to the map we've only gone 4 inches."

Harry Dunne. *Dumb & Dumber.* (movie, 1994)

"Just a map! Maps, my dear, are the undergarments of a country!"

Morgan the Goat. *The Englishman Who Went Up a Hill But Came Down a Mountain.* (movie, 1995)

more information...

An accessible introduction to map projections is *Seeing Through Maps: The Power of Images to Shape Our World View,* by Ward Kaiser and Denis Wood (ODT, 2001).

A great handbook describing and illustrating dozens of map projections is *An Album of Map Projections,* published by John Snyder and Philip Voxland as a U.S. Geological Survey Professional Paper (#1453, 1989).

The best book on map projections is John Snyder's *Flattening the Earth* (University of Chicago Press, 1997). Snyder's approach is historical and exhaustive. The treatment is technical but not intimidating.

Every cartography textbook has a chapter or two on map projections and coordinate systems. The map projection chapter in Borden Dent's *Cartography: Thematic Map Design* (Brown, 1998) has a good chapter on map projections, and Phillip and Juliana Muehrckes' *Map Use* (JP Publications, 1998) has a good chapter on coordinate systems.

Sources: The body projection on pp. 88-91 and 97 courtesy of Lilla Locurto and Bill Outcault. The majority of map projections in this chapter were generated in GeoCart software, and a few in ArcGIS. The idea for the flat toad (p. 94) is borrowed from Edward Tufte, *The Visual Display of Quantitative Information* (Graphics Press, 1983). The map of vegetation on a Mercator map projection (p. 98) is based on a map in Anne Spirn's *The Granite Garden: Urban Nature and Human Design* (Basic Books, 1984). Delaware County, Ohio, data (p. 113) courtesy of the DALIS Project. The State Plane Coordinate and Universal Transverse Mercator diagrams (pp. 115-116) were re-created from the Muehrckes' *Map Use* (1998) and Kraak and Ormeling's *Cartography* (Pearson, 1996). Lyrics to *Map Ref. 41°N 93°W* written by Graham Lewis, Colin Newman, Bruce Gilbert used by permission of Carbert Music Inc.